W72-03236

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# IRON-59 AS A SOLIDS TRACER IN AQUEOUS SUSPENSIONS

by

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U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

October 1967

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

1. Report No.

2.

3. Accession No. W72-03236

4. Title IRON-59 AS A SOLIDS TRACER IN AQUEOUS SUSPENSIONS,

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s) Scalf, M. R., Witherow, J. L., and Priesing, C. P.

10. Project No. FWPCA Project 16020 - - - 10/67

9. Organization Federal Water Pollution Control Admin, Ada, Okla, Robert S. Kerr Research Center.

11. Contract/Grant No.

13. Type of Report and Period Covered

12. Sponsoring Organization

15. Supplementary Notes Robert S. Kerr Water Research Center Report, Federal Water Pollution Control Administration, October 1967. 32 p, 8 fig, 2 tab, 15 ref, append.

16. Abstract Tracer methods using iron-59 were devised for silt tracing in rivers and reservoirs, suspension tracing in lagoons, and sludge handling processes. Iron-59 almost completely adheres to particulate matter when introduced into a sewage suspension. When using iron-59 as a tracer in systems which recirculate solids, an excessive tailing effect may be expected on the dispersion curve unless the recirculated radioactivity is measured and subtracted. Iron-59 has two hard gammas, one at 1.098 Mev and another at 1.289 Mev. In addition, it has two strong betas which allow the beta counting of samples collected. Iron-59 has a half life of 45.1 days which is sufficient time for preparation, experimentation, and later analyses of samples at the laboratory. (Woodard-USGS)

17a. Descriptors *Water pollution sources, *Pollutant identification, *Tracking techniques, *Tracers, *Path of pollutants, Analytical techniques, Silting, Sewage, Sludge, Solid wastes, Silts, Suspended load.

17b. Identifiers *Iron-59 (solids tracer), Aqueous suspensions.

17c. COWRR Field & Group 05A, 05B, 05C

Available from the National Technical Information Service as PB 205 827, $3.00 in paper copy, $0.95 in microfiche

18. Availability

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

Send To:
WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
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Abstractor T. H. Woodard 1/10/72

Institution U.S. Geol. Survey, Water Res. Div.

# IRON-59 AS A SOLIDS TRACER IN AQUEOUS SUSPENSIONS[a]

By M. R. Scalf,[b] J. L. Witherow,[c] and C. P. Priesing[d]

## INTRODUCTION

Detention time is of primary importance in many waste treatment processes and probably the most universal design standard. The purpose of this paper is (1) to introduce a radiotracer for determining the detention of particulate matter in hydraulic systems and (2) to demonstrate simple, fast, and reliable methods of combining this tracer with dye tracers to determine the hydraulic performance of sewage treatment processes.

The investigations discussed herein were initiated to determine particulate detention and hydraulic performance in field research at San Antonio, Texas. High removals of soluble phosphate realized by one of the three activated sludge systems were accomplished in the

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[a]Presented at the October 6-7, 1967, ASCE Meeting, Texas Section, held at Abilene, Texas.

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aeration tanks by sorption from the liquid to the mixed liquor solids. The efficiency of the process was found to be controlled by several operational parameters including aeration detention time and solids detention time in the final clarifier.[1,2] The need for tracer research arose because these two parameters presented problems in quantification.

The studies at San Antonio indicated that the waste should receive, as the minimum, two to three hours' aeration to accomplish phosphate sorption in the activated sludge process. This was most efficiently realized in batch systems or in continuous systems approaching plug flow.

The aeration basin is designed primarily to maintain bacteria in a suitable environment for the utilization of organic matter and to generate biological floc which can be separated from the liquid in the final clarifiers. Phosphate removal is dependent upon the time of aeration in the presence of bacteria. Mixing conditions in the aeration tank greatly influence the detention time and, thus, the phosphate removal efficiency of the basin. Short circuiting decreases hydraulic efficiency, phosphate removal, organism growth,[3] and the settling and compactability properties of the activated sludge. A poor settling activated sludge will degrade the quality of the final effluent and reduce the return sludge concentration which, upon recycle, will adversely affect the mixed liquor suspended solids concentration.

If the final clarifiers likewise exhibit appreciable short circuiting, the solid-liquid separation is further decreased to the detriment of the phosphate removal efficiency and the return sludge quality.

The design of many aeration basins and final clarifiers is based on standard detention times recommended by state health departments. Excessive emphasis is placed on the volume of the basin, and sometimes too little attention is given to other critical design parameters. The need is to determine the hydraulic efficiency or actual detention of a basin in order to predict nutrient removal efficiency.

Evaluating the hydraulic characteristics of the treatment basins at San Antonio also established the feasibility of slug-flow sampling. The slug-flow method of investigation consists of sampling and measurement at several locations in the process stream at time intervals proportional to the displacement times between those locations. The validity of this technique is dependent upon sampling the effluent end of a basin at a time when sample collected is most representative of the waste slug sampled at the influent end. This elapsed time is the modal detention time and is always less than the theoretical detention time, i.e., the time obtained by dividing the tank volume by the flow rate. Modal detention times must be determined from tracer studies.

Dye tracers for liquid detention time or time of travel studies have been used extensively by other investigators and proved useful in evaluating liquid movements in sewage treatment basins.[4,5,6] However, because sewage treatment necessarily employs the separation

of solids from liquids, a separate tracer technique was required for determining the hydraulic characteristics of the particulate matter. A radioactive tracer, iron-59, was used successfully for this purpose.

## SELECTION OF TRACERS

Fluorescein dye was the first dye selected as a tracer for the liquid mass. This particular dye was chosen, primarily, because it was available and, secondarily, because it was nontoxic and low in cost. Since the background fluorescense of sewage is near the same wavelength of fluorescein dye, the dye was difficult to detect and quantitate. Rhodamine dyes were used in later studies.

Rhodamine B was used at one location for detention studies of aeration tanks and final clarifiers; however, Rhodamine B does exhibit appreciable adsorption on solids and, consequently, cannot be used strictly as a quantitative tracer of the liquid mass. Rhodamine WT was used at several locations and has become the tracer most commonly used by this Center for liquid tracing. Rhodamine WT not only fluoresces at wavelengths not normally found in natural water but was developed for low adsorptive properties on suspended matter.

The separation of solids from liquids is an integral part of the sewage treatment process; therefore, the hydraulic characteristics must be determined for the solids as well as the liquids. Since other tracers are generally designed for determining liquid movement, efforts were begun to find a radioisotope for solids tracing.

A detection system that could measure radioisotope concentrations in situ was desirable because actual detention times were sometimes needed immediately for subsequent studies. Penetration of alpha and beta radiation is slight, and counting equipment requires extensive shielding; therefore, a gamma emitter was desirable from a detection consideration.

Because gamma radiation is much more penetrating than alpha or beta radiation, sensitive detection systems such as scintillation counters do not require great amounts of shielding and are much more adaptable to field studies than alpha or beta counting systems. Gamma emitters are also desirable because measurements can be made without taking samples or being in contact with the liquid; one example is a measurement made through a sewer pipe.

The large sample volume made available by in situ counting systems and the very sensitive gamma detection systems make it possible to measure very small amounts of activity per unit volume. Less radioactive material is required for the system which, in turn, reduces cost and health hazards. Health hazards are further reduced because of the ease of monitoring gamma contamination.

The isotope half life must also be considered when selecting a radioactive tracer. It must be long enough to allow sufficient time for receipt from the factory, tracer preparation, application, and analysis. It must also be short enough to minimize radioactivity levels from a public health viewpoint and to reduce the background for succeeding tests.

Equally important considerations for these experiments were the chemical and physical form of the radioisotope. It was desirable, first, that the isotope be in water soluble form for ease of preparation, handling, and application and, second, that the ionic species employed become strongly attached to the suspended solids phase upon introduction to the activated sludge system. Metal ions such as those of iron and aluminum were considered first because of their recognized use as coagulants in water and waste treatment. Iron-59 isotope has also been used in analogous aqueous suspensions including bauxite[7] and river muds.[8]

After consideration of the above requirements, iron-59 was selected as the radioactive tracer most suitable for these experiments. Iron-59 has two hard gammas, one at 1.098 Mev and another at 1.289 Mev. In addition, it has two strong betas which allow the beta counting of samples collected. Iron-59 has a half life of 45.1 days which is sufficient time for preparation, experimentation, and later analyses of samples at the laboratory.

The chemical characteristics of iron are also desirable. At pH <4, the cationic ($Fe^{3+}$) form predominates while the cationic hydrated metal ions are more prevalent at pH 4-6.[9] Optimum coagulant activity occurs in this latter range where the hydrated metal ions may adsorb to and flocculate the biomass.[10] The anionic hydrated metal ions are more common at pH >6 and with increasing pH there is an increased tendency toward hydrated oxide precipitation such as $Fe(OH)_3$.

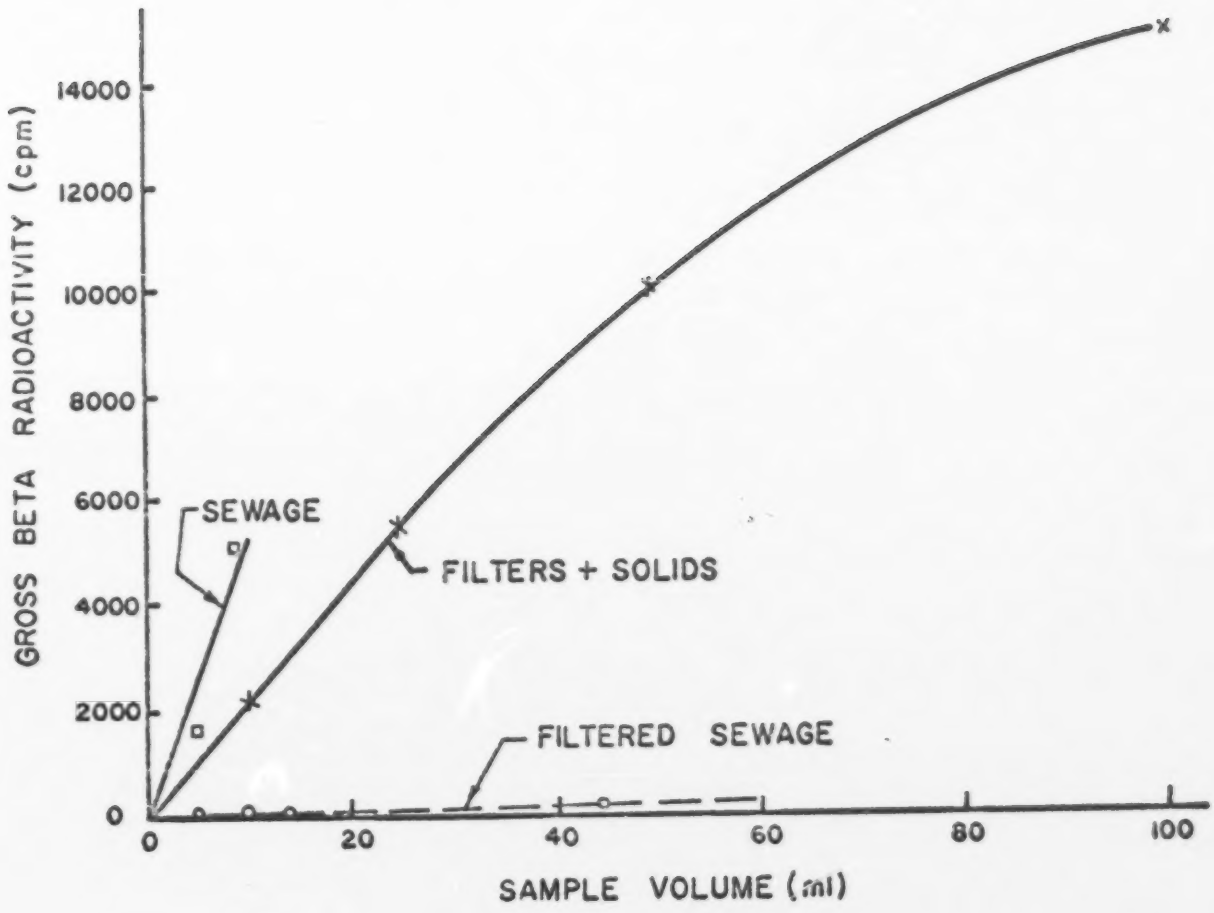


FIGURE 1. ADSORPTION CAPACITY OF IRON-59 ON SEWAGE SOLIDS

The balance between adsorption and precipitation is somewhat precarious at pH 6-8, the range common to most municipal sewages. Higher concentrations of hydrolysis products are known to appear with increasing concentration of ferric ion but even the hydroxide precipitates tend to adsorb to suspended solids.

The affinity of iron-59 for particulate matter is demonstrated in Figure 1. Some of the radioisotope was added to a flask containing sewage from an aeration tank of a sewage treatment plant. The sewage

contained about 2,000 mg/1 of suspended solids. The contents were mixed in the flask by shaking for a brief period. Two samples of the mixture were dried in stainless steel planchets, and the beta activity was counted in an internal proportional counter. Various quantities of the remaining mixture were filtered through Whatman No. 41 filter paper, and the dried filters and solids were beta counted in the identical manner. Various quantities of the filtrate were also dried and beta counted in the same manner as the mixed liquor and the filter papers.

Very little of the radioactivity was found in the filtrate, indicating that essentially all of the tracer material attached permanently to the solids.

The apparent loss of activity by filtering the sewage-radioisotope mixture, as indicated by the difference between the sewage curve and the sum of the other two curves, can be attributed to absorption of beta particles by the filter media. Similarly, the nonlinearity of activity at higher sample concentrations is caused by a buildup of solids on the filters and a resultant self-absorption of beta activity.

## TRACER TECHNIQUES

### Dyes

Dye tracer studies were conducted using technical grade fluorescein (Uranne W. SS.) and a Rhodamine WT 20 percent solution. The fluorescein dye was dissolved in about 3 gallons of water with the addition of ethyl alcohol to enhance solubility. The rhodamine solutions were simply diluted to 3 gallons. After dilution, the dye was added as a slug to the unit process being studied.

A Turner Model 111 Fluorometer equipped with #110-811 (7-60) primary and #110-816 (2A) secondary filters was used for fluorescein measurements. A combination of primary, #110-814 (1-60) plus #110-822 (58), and secondary, #110-824 (23A), filters was used for rhodamine measurements.

Calculations for dye tracers are usually empirical as was the case in these studies. These experiments indicated that about 100 ppb of fluorescein or rhodamine dye, averaged over the volume of the system studied, was necessary to obtain sufficient detection concentrations in the sewage effluent samples measured.

Radioisotope

Radioisotope, received in the form of 0.5 or 1.0 normal ferric chloride solution, was diluted for ease of handling. A measured amount was introduced with stable ferric chloride as a carrier into the process being studied.

With predominantly organic suspensions at pH 7-8 (sewage), the addition of trace quantities of $Fe^{3+}$, radioactive or otherwise, would (1) lead to the rapid formation of hydrolysis products, some of which will adsorb to the biomass, (2) precipitate as $Fe(OH)_3$, or (3) form complexes with other inorganic moities such as the phosphate ion. The use of a carrier solution promotes iron-59 adsorption by increasing the total concentration of $Fe^{3+}$ and the chance of intermediate hydrolysis products which can adsorb to the solids surfaces. The carrier solution also acts to disperse the critical isotope in the medium by preventing localized overadsorption, but the total quantity applied is negligible with respect to coagulation of the total biomass of the system being studied.

Monitoring of radioactivity was accomplished using two gross gamma counters* connected by 10-foot cords to a cesium iodide or a sodium iodide scintillation detector inside a plastic pipe, as shown in Figure 2. The pipe was sealed on one end and immersed in the liquid at the location of interest. Placing the detector about 4 feet below the surface of the water reduced the natural background count rate almost 90 percent. The voltage discriminators of the counting system were set so that only those gamma emissions with energies greater than 1.0 Mev were counted.

In one tracer experiment on a final clarifier, dip counting was not feasible but the hard gamma radiation of iron-59 made possible another type of monitoring. The scintillation detector was placed beside the return sludge pipeline and the radioactivity was monitored through the pipe wall.

Samples were collected at monitoring locations during many of the radiotracer experiments. These samples were returned to the laboratory and prepared for beta counting by drying a 20 ml portion in a stainless steel planchet. Beta counting was performed in an NMC** PC 3-T Proportional Counter.

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*Constructed and provided by Mr. Richard Stoms, U. S. Public Health Service, Cincinnati, Ohio.

**Nuclear Measurements Corporation.

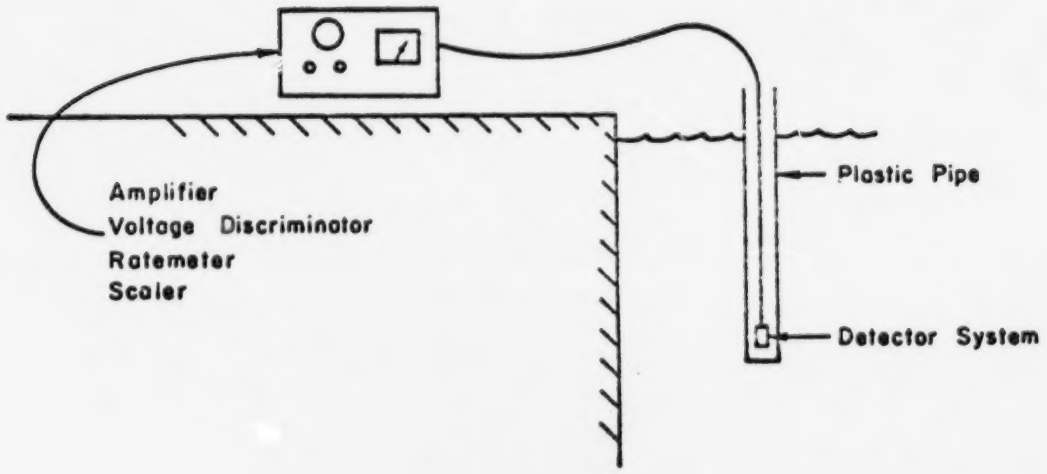


FIGURE 2. GAMMA RADIOACTIVITY MONITORING SYSTEM

The first experiment carried out using iron-59 was the determination of solids detention time in a circular final settling tank. The tank volume was 1.3 million gallons, and the approximate flow rate was 15 million gallons per day (MGD). Since information was unavailable on the efficiency of unshielded dip-counting with scintillation detectors, determination of the amount of radioisotope to add was made on a theoretical basis. Preliminary calculations were necessary to determine the activity required for statistically meaningful measurements as well as to determine the specific activity of the waste effluent into uncontrolled areas in order to meet safety requirements.

The radiation reaching the detector, $A_I$, in a dip-counting arrangement is estimated by assuming a spherical detector with a radius, R, calculated from the detector volume and a hemispherical sample with an inside radius $h_1$ and outside radius $h_2$. Allowing for sample self-absorption, the relation to the volume specific activity, $A_v$, may be expressed as:

$$A_I = \frac{A_v \pi R^2}{2} \int_{h_1}^{h_2} e^{-\mu (r-h_1)} dr \qquad (1)$$

For very large samples, this equation may be reduced to:[11]

$$\frac{\text{cpm (observed)}}{\text{dpm/liter}} = \frac{(A)\ (y)\ (E)}{8\mu} \qquad (2)$$

r = distance from some point in sample to the detector

$\mu$ = gamma absorption coefficient in water = 0.06 for iron-59

A = surface area of detector = 156 square inches (2 x 2 in crystal)

y = detectable radiation yield per disintegration = 1.0 (iron-59)

E = counter efficiency (assumed to be 0.01)

The background of the counters was assumed to be 500 counts per minute, and a sample count rate of 10 times this was desired for statistical reliability. The theoretical detention time in the final clarifier was about 4 hours. The greatest possible dilution of the radioisotope was assumed to be complete mixing in a 4-hour period. Using the above formula, the specific activity required was calculated to be

$$\text{Activity} = 5000\ (8)\ (.06)/[156\ (1)\ (.01)] = 1530 \text{ dpm/liter}$$

$$= 7 \times 10^{-7} \text{ microcuries/milliliter } (\mu c/ml)$$

$$\approx 7 \text{ millicuries/1.3 million gallons}$$

From this estimation, 10 millicuries was selected for the initial application of iron-59 radiotracer. Subsequent radiotracer studies indicated that about 5 millicuries of iron-59, per each million gallons volume of basin studied, provided effluent concentrations readily measurable by dip-counting with sodium or cesium iodide scintillation detectors.

Any proposed use of radioisotopes as tracers must include calculations of concentrations to be released to unrestricted areas. The maximum quantity of iron-59, averaged over a 24-hour period, which may be released to a sanitary sewer is $6 \times 10^{-5}$ µc/ml.[12] Ten millicuries averaged over a 15 million gallon flow is only $1.8 \times 10^{-7}$ µc/ml or about one three-hundreth (1/300) of the maximum allowable concentration.

## EXPERIMENTAL RESULTS

### Final Clarifiers

The detention times of solids and liquids in final clarifiers of various treatment plants were determined by introducing iron-59 radiotracer and rhodamine dye into the clarifier influent and monitoring the final effluent and return sludge.

The primary objectives of tracer studies for final clarifiers were the times of peak tracer concentrations and the percent of incoming waste short circuited to the return sludge outlet.

Figure 3 presents the results of radioactivity measurements of the return sludge by monitoring with a gross gamma counting system attached to a sodium iodide scintillation detector. These measurements indicated a sharp peak in radioactivity within the first 10 minutes after addition of the radioisotope to Clarifiers (a), (b), and (d). This peak represents short circuiting of the particulate matter in the mixed liquor directly to the return sludge outlet and indicates little or no sludge blanket formation in the final clarifier. All four clarifiers were designed such that the return sludge outlet pipe and the mixed liquor inlet pipe are located very close together; however, Clarifier (c) was operating with a sludge blanket depth greater than 5 feet. Test conditions are presented in Table 1.

TABLE 1

Radioactive Tracer Test Conditions, Final Clarifiers

| Clarifier | a | b | c | d |
|---|---|---|---|---|
| Iron-59 (mc) | 10.0 | 5.0 | 3.4 | 2.5 |
| Flow (MGD) | 15.0 | 9.0 | 3.7 | 10.0 |
| Tank Volume (MG) | 1.3 | 0.8 | 0.8 | 1.1 |
| Return Sludge (MGD) | 4.8 | 1.7 | 1.1 | 2.1 |
| Detector | Dip* | End** | Dip | Dip |

* - Dip-Counting Arrangement

** - Unshielded Detector Lying Beside the Return Sludge Pipe

The second peak in Clarifiers (a) and (b) and, possibly, (d) and the only peak in Clarifier (c) is a result of the sewage spreading

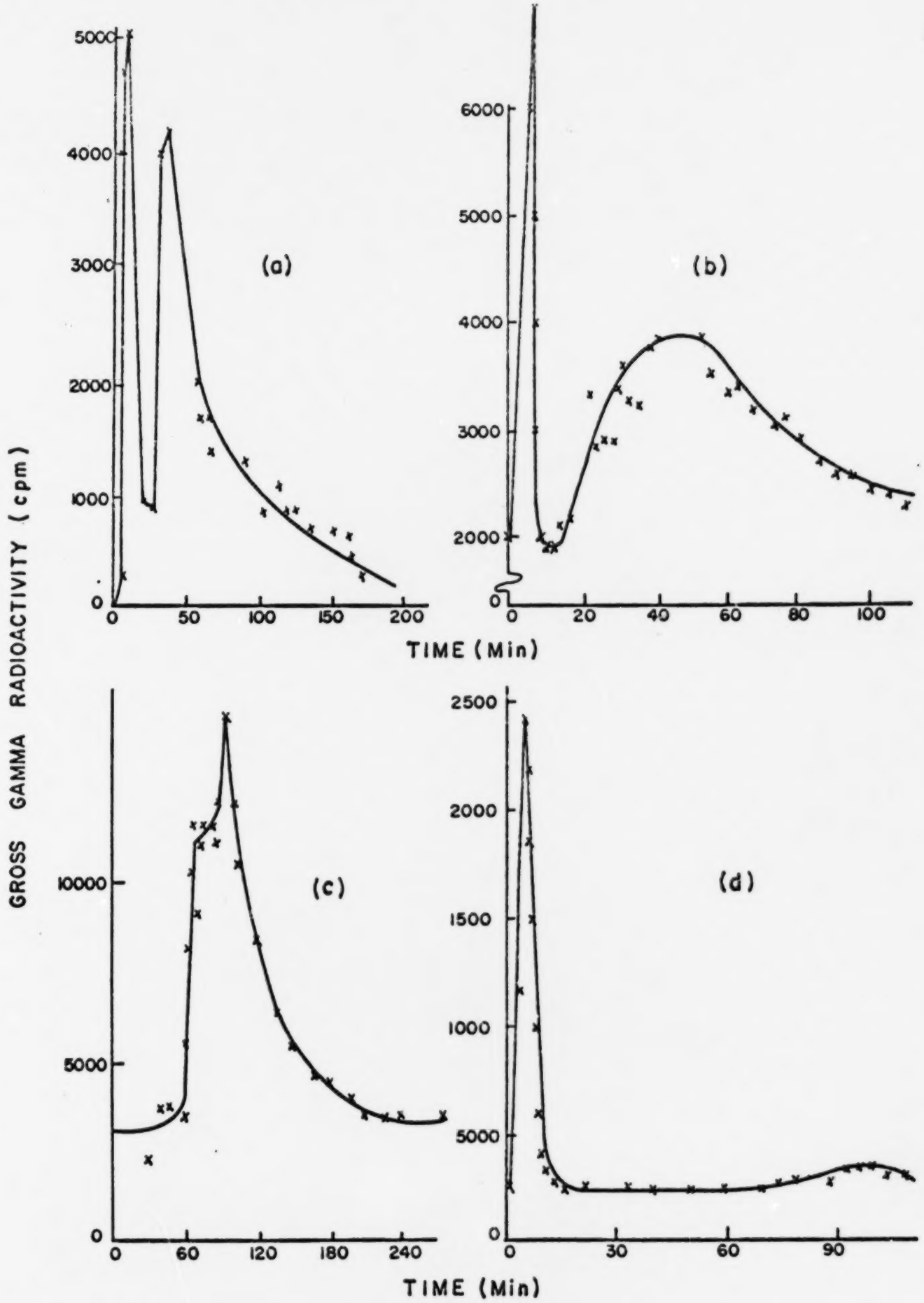


FIGURE 3. RETURN SLUDGE RADIOTRACER DISPERSION CURVES

throughout the tank, the particulate matter tagged with iron-59 settling to the bottom and being raked into the return sludge outlet.

The relative areas under these double curves provides a measure of the percent short circuiting of incoming particulate matter.

The operation of the final clarifiers is as important as the design. All four clarifiers were of similar design; that is, all were of the center feed, radial flow type; however, short circuiting may have accounted for as much as 50 percent of the particulate matter coming into Final Clarifier (d). Clarifier (c) indicated no short circuiting of particulate matter and almost plug-flow conditions as a result of stratification in a deep sludge blanket.

Although radiotracer recovery* is a simple procedure, recovery was not fully successful during these investigations for two reasons: (1) in situ monitoring by dip-counting makes counting efficiency determination difficult at best and (2) the activity of most samples collected for beta counting was too low for statistically reliable counts on the instrument available (background 50 cpm).

The geometry of the detector system is the most important variable affecting dip-counting efficiency. The relation of the detector to the walls and bottom of the container and to the surface of the liquid make it extremely difficult to determine the

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*Recovery $= q \int_{t_1}^{t_2} c \, dt$, where q = flow, c = concentration of tracer, t = time.

true volume of sample being counted. The density of the liquid or the particulate matter present may be responsible for absorption of gamma photons, thereby reducing the effective volume of sample.

An easier and more reliable method of determining iron-59 recovery is to collect samples and determine the activity in low-background gamma or beta counting laboratory instruments. The efficiencies of these instruments can be determined simply by counting a sample of the isotope with a known activity. This approach was attempted during these studies.

A 20 milliliter sample was dryed in a stainless steel planchet and counted for 10 minutes in an internal proportional counter; however, the maximum activity encountered in any of the samples was less than 10 μμc/ml or 100 cpm, and the other samples were substantially less than this value. The background of the instrument used was too high to obtain statistically reliable results from most of these low activity samples without prohibitively long counting periods. There are available counting instruments which have background counting rates of 1.0 cpm or less. The value of low background is shown by the equation for counting error at the 95 percent confidence limit.

$$E_{95} = 2\sqrt{\frac{N_{S+BG}}{t_{S+BG}} + \frac{N_{BG}}{t_{BG}}}$$

$N_{S+BG}$ = Count rate of the sample plus background

$t_{S+BG}$ = Counting time of sample

$N_{BG}$ = Count rate of the background

$t_{BG}$ = Counting time of background

It is obvious that combinations of higher activity, reduced background, and increased counting time will reduce the relative counting error; however, the practical upper limit on radioactivity added to the system and on sample counting time for most field applications makes the low background instruments more desirable than the other variables.

The results of beta counting return sludge samples from tracer studies on one final clarifier are shown in Figure 4. The similarity of the beta activity curve to the gross gamma curve from in-situ monitoring demonstrates the feasibility of determining tracer recovery by beta counting samples. Since radioactivity in the final effluent was not detectable by either method of measurement, essentially all of the tracer could be expected to be recovered in the return sludge of a clarifier with adequate solid-liquid separation.

The significance of using separate tracers for the liquid and particulate portions of a system is demonstrated in Figure 5. Both Rhodamine WT and iron-59 were added to the influent of a final clarifier at the same time and the return sludge was monitored for fluorescence and radioactivity and the final effluent for fluorescence.

None of the dispersion curves indicates significant short circuiting. The radioactivity curve shows very sharp ascending and descending slopes which indicate almost plug-flow conditions in the return sludge due to stratification of the particulate matter in the final clarifier. The return sludge dye curve exhibits a broader base and narrower peak. This curve is probably a result of liquid that

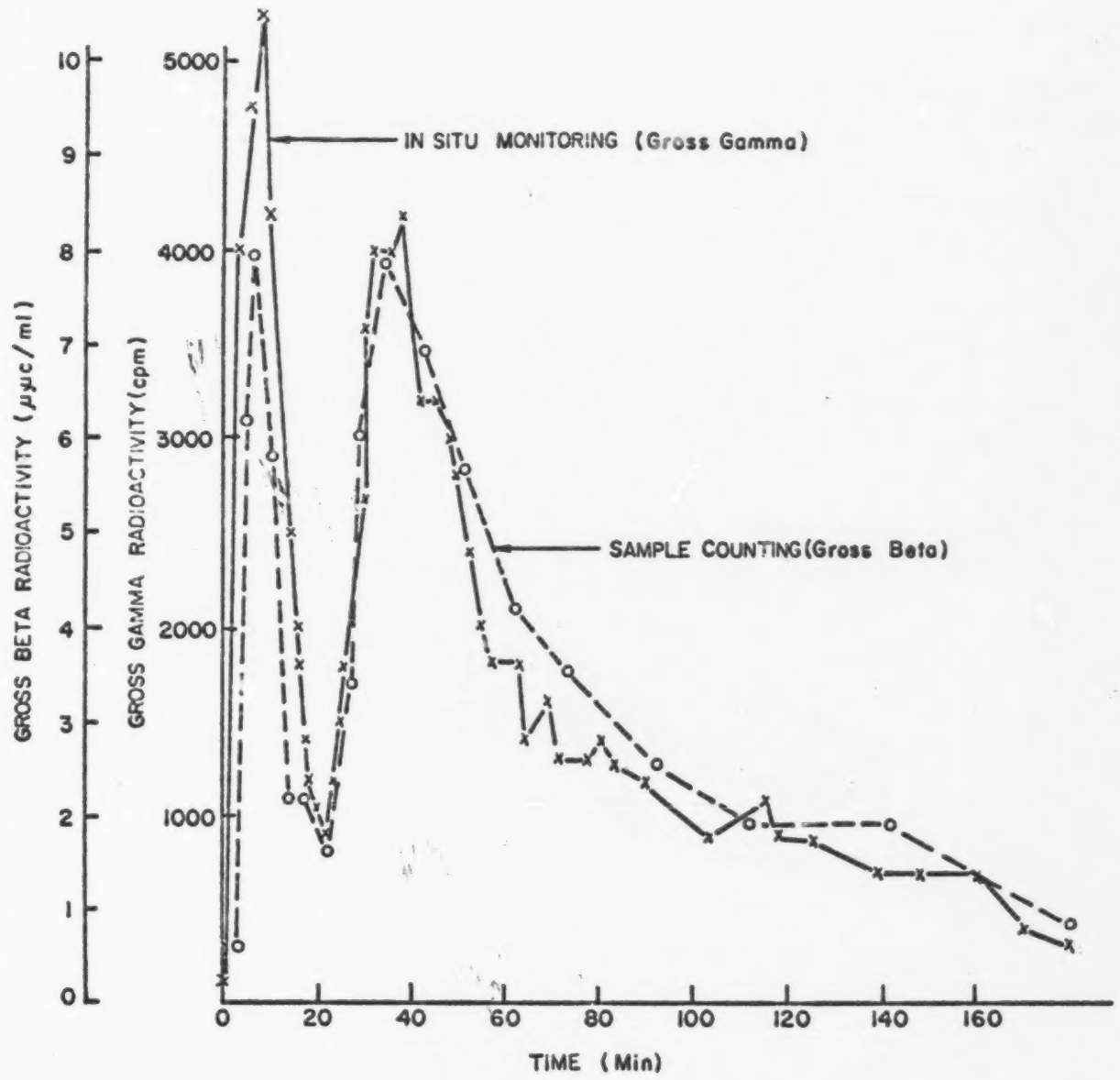


FIGURE 4. COMPARISON OF SAMPLE BETA COUNTING WITH IN SITU GAMMA COUNTING

was trapped among the solids rather than dye adsorbed on the particles. The peak dye concentration also occurs almost one-half hour after the peak radioactivity concentration, indicating that the solids travel faster through the sludge blanket than does the liquid mass.

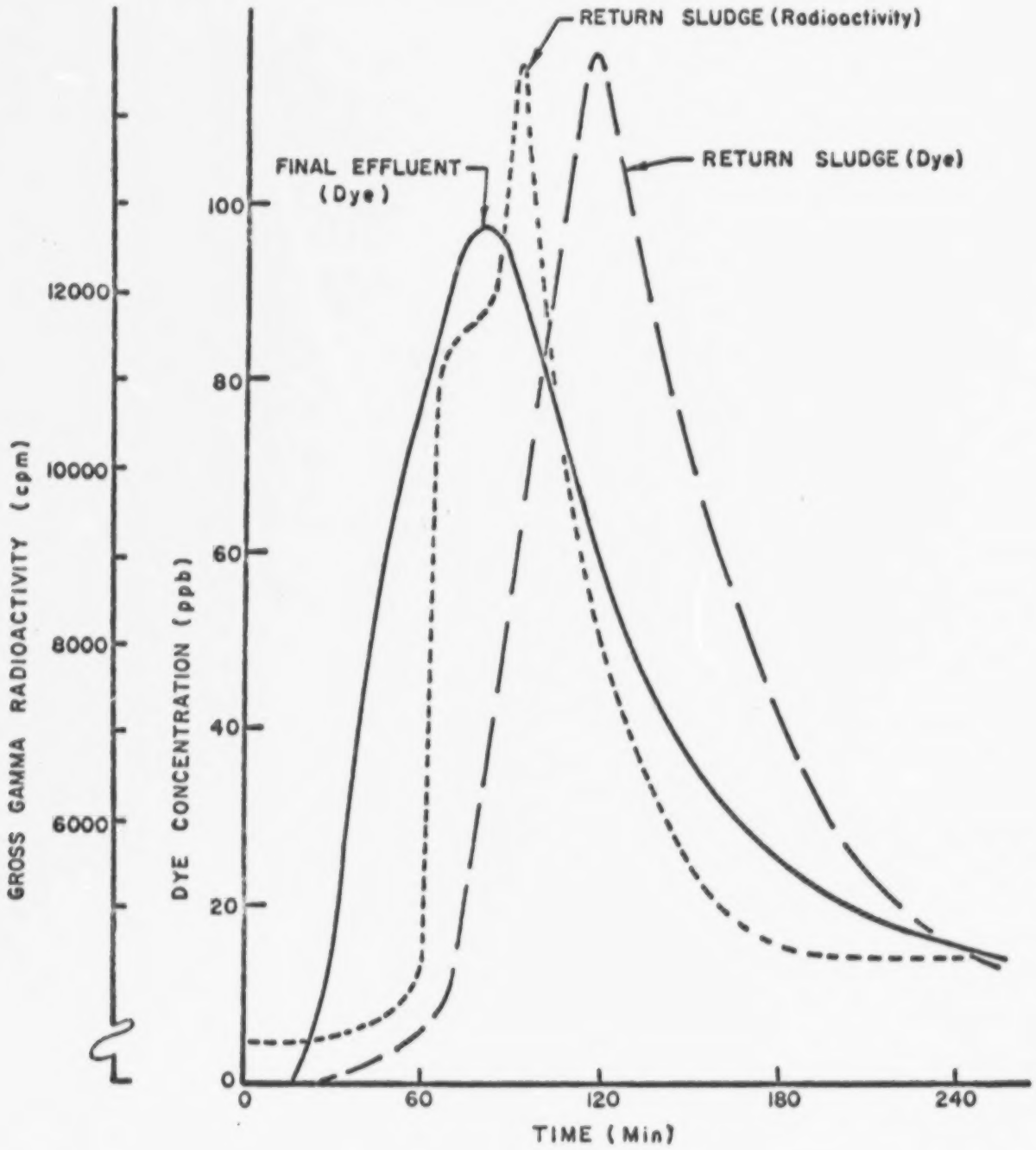


FIGURE 5. DETENTION OF SOLIDS AND LIQUIDS IN A FINAL CLARIFIER

Aeration Tanks

There are various methods available for analyzing tracer dispersion curves, from casual visual interpretation to exotic computer programs which may enable the prediction of the performance of an activated sludge unit with respect to nutrient utilization and organism growth. The object of these methods is a description of the hydraulic characteristics of the basin, notably, the extent of longitudinal mixing or short circuiting.

The primary objective of aeration basin tracer studies was the determination of the proximity of the hydraulic conditions in the basin to plug-flow. A tank with ideal plug-flow would exhibit a dispersion curve such as the vertical line B in Figure 6. Curve A is the theoretical curve for a completely mixed basin in which the tracer is introduced and instantaneously mixed throughout the tank. Something between these two extremes, such as Curve C, can be expected for an actual aeration basin.[13] The value T is the theoretical detention time, $C_o$ is the total tracer averaged over the volume of the tank, and C is the effluent tracer concentration at any time t.

Although many aeration basins are designed with Curve B in mind, the actual hydraulic characteristics are altered by (1) the length-width ratio, (2) the number of compartments, (3) the type, number, and arrangement of air diffusion devices, and (4) the quantity of air applied. The results are tracer dispersion curves,

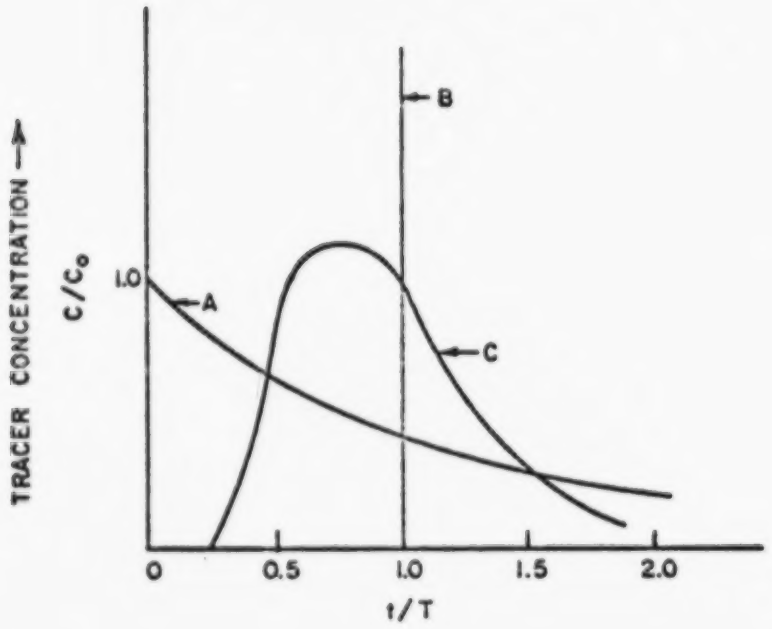


FIGURE 6. TRACER DISPERSION CURVES

such as Curve C, which may be caused by stagnant zones in the basin, short circuiting, errors in determining theoretical detention times, partial complete mixing, partial plug-flow, or any combination of these.[14]

Both iron-59 radiotracer and rhodamine dye were used in tracer studies of aeration basins of activated sludge sewage treatment plants. Dimensionless parameters used to describe the resultant tracer dispersion curves and, thus, hydraulic efficiency are $t_1/T$, $t_p/T$, $t_m/T$, and $t_{90}/t_{10}$. The value $t_1$ is the time of first tracer appearance in the effluent; $t_p$ is the peak or modal detention time; $t_m$ is the mean detention time or centroid of the dispersion curve; T is the theoretical detention time (volume/flow rate); and $T_{10}$ and $t_{90}$ are the times of passage of 10 and 90 percent, respectively, of the tracer. The ratio $t_1/T$ is a measure of the worst short circuiting in a basin; $t_p/T$

is a measure of volumetric efficiency; $t_m/T$ is a measure of short circuiting due to stagnant zones and longitudinal mixing; and the dispersion ratio, $t_{90}/t_{10}$, is a measure of the uniformity of flow through the basin.[15] For an ideal plug-flow system, all these parameters would be equal to 1.0.

In the only study where both radiotracer and dye were used to determine detention time in the same aeration tank, 1.0 millicurie of iron-59 and 3 pounds of fluorescein dye were introduced into the influent and monitored in the effluent of the basin. The most significant characteristic of the resultant dispersion curves is the difference in ascending slope and modal detention times, as shown in Figure 7. These differences indicate that the particulate matter, represented by the radioactivity, traverses the tank faster than the liquid which is represented by the dye.

Since the detention time of the liquid waste in aeration tanks is usually of more interest than solids detention, dye was used as the tracer in all the remaining aeration basins investigated except one. Some of the resultant dispersion curves are presented in Figure 8, and descriptive parameters are noted in Table 2. Conditions represented range from near plug-flow, as in Tank A, to hydraulic conditions approaching complete mixing, as in Tank D.

Four (4) millicuries of iron-59 were used as the tracer in Tank B. Rhodamine WT dye was used as the tracer for Tanks A, C, D, and D' in amounts of 1,000, 300, 400, and 400 grams, respectively.

Dye tracer data from Tank B were not available for comparison with the radiotracer dispersion curve; therefore, three factors should be kept in mind while comparing Curve B with dispersion curves from the other tracer studies using dye tracer. First, the ordinate for Curve B is C/Cp where Cp is the maximum tracer concentration. Second, as noted previously, the particulate matter can be expected to traverse the tank faster than the liquid. At least the ascending portion of Curve B would be expected to be displaced to the right if dye had been used as the tracer. Third, essentially all of the radiotracer is adsorbed to the particulate matter; and, the only outlet of the solids

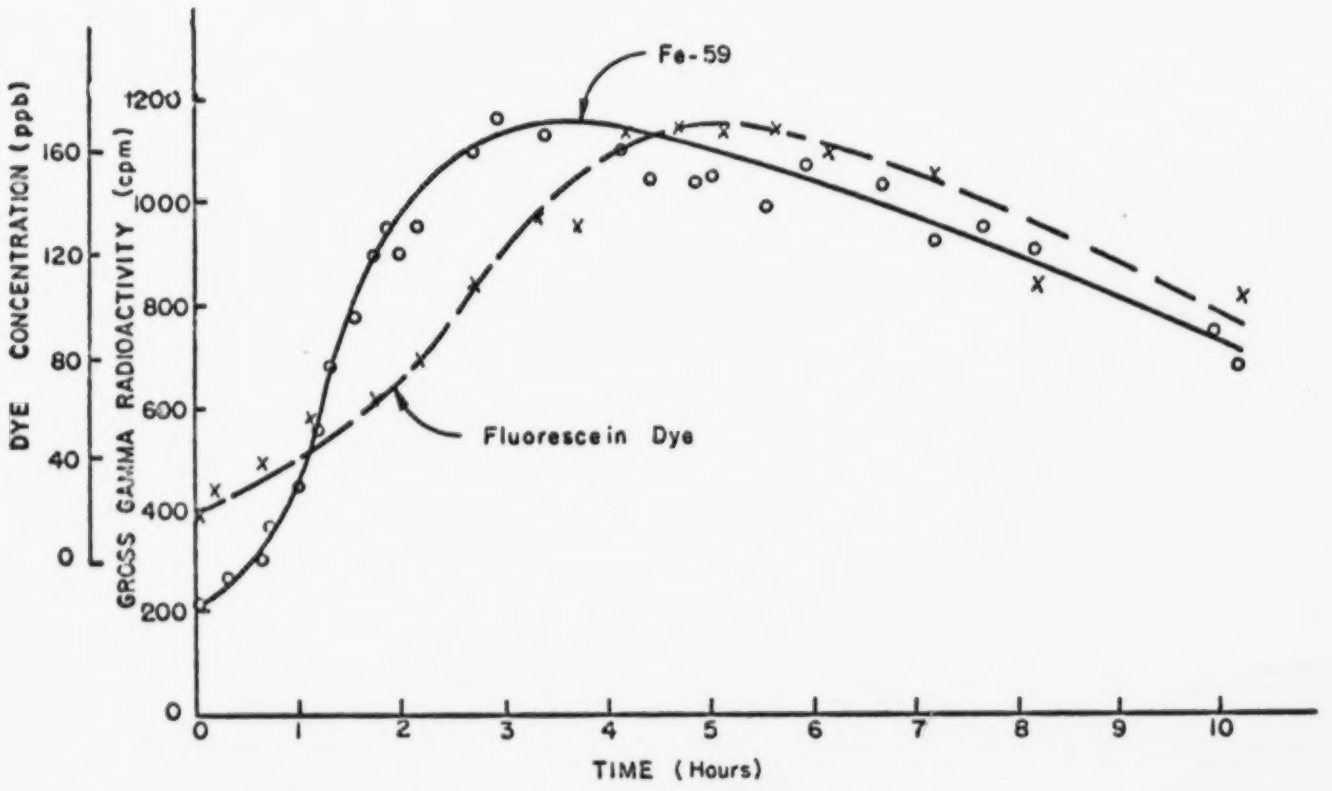


FIGURE 7. COMPARISON OF FLUORESCEIN DYE AND IRON-59 AS TRACERS IN AERATION TANKS

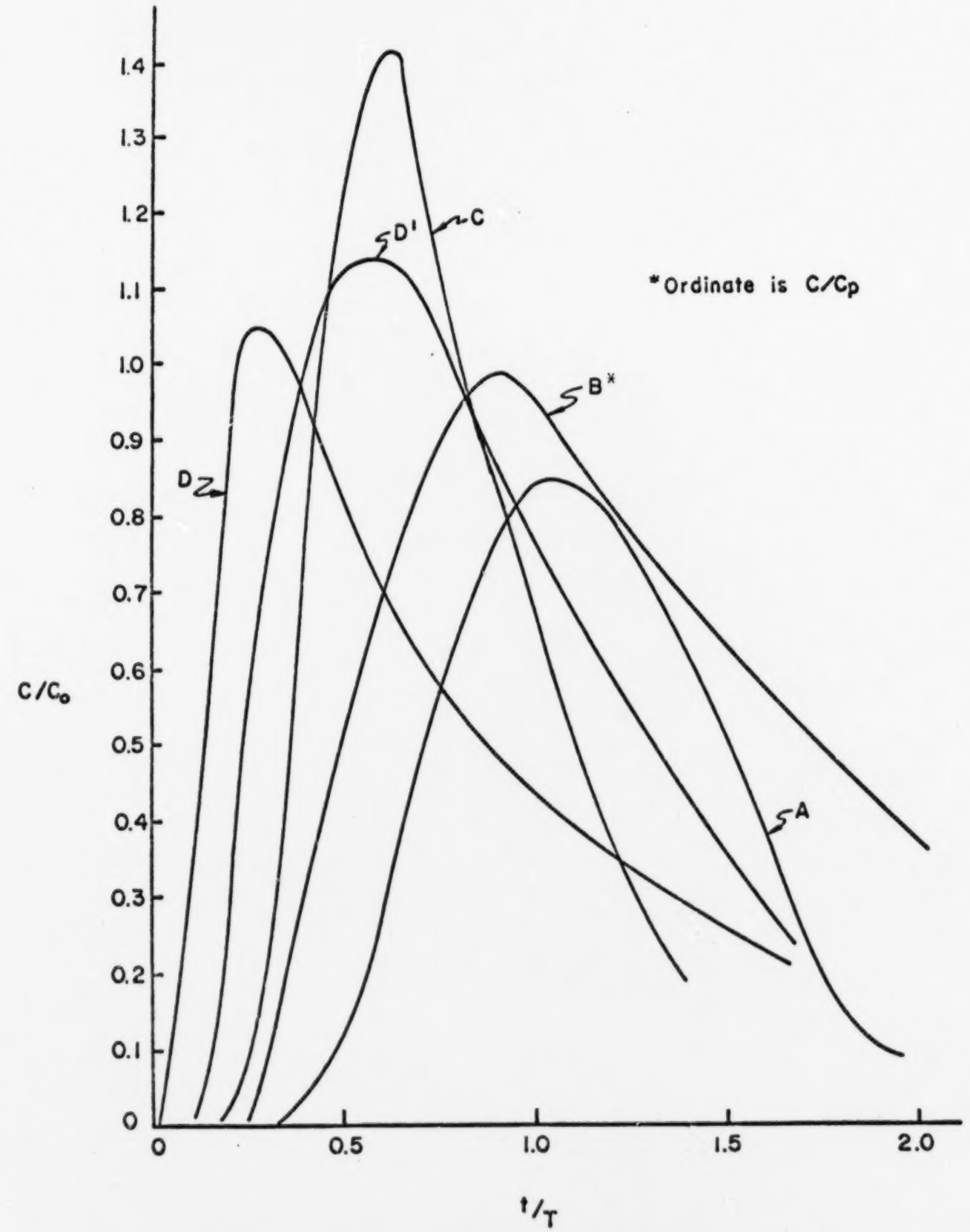


FIGURE 8. TRACER DISPERSION CURVES FOR AERATION TANKS

system is approximately one MGD of waste sludge. Since a large portion of the dye tracer is removed from the system with the final effluent, recirculation of dye tracer is insignificant in comparison to recirculation of iron-59 tracer. Recirculation of radioactive sludge was responsible for the long tailing effect of Curve B. If rhodamine dye were used in Tank B, a dispersion curve very near Curve A could be expected.

TABLE 2

Comparison of Tracer Dispersion Curve Characteristics of Some Aeration Tanks

| Aeration Tank | A | B | C | D | D' |
|---|---|---|---|---|---|
| Length:Width | 25:1 | 20:1 | 18:1 | 9:1 | 9:1 |
| Volume (mg) | 2.6 | 1.93 | 0.59 | 0.62 | 0.62 |
| Type | 2-pass* | 2-pass | 2-pass | 1-pass | 1-pass |
| T (Hours) | 4.6 | 8.6 | 6.3 | 4.4 | 3.8 |
| $t_1/T$ | 0.4 | 0.3 | 0.19 | <0.05 | 0.13 |
| $t_p/T$ | 1.0 | 0.9 | 0.6 | 0.3 | 0.6 |
| $t_m/T$ | 1.2 | 1.2 | 0.7 | 0.8 | 0.9 |
| $t_{90}/t_{10}$ | 2.4 | 3.5 | 2.5 | 8.5 | 6.4 |

*Actually two tanks in series.

Curve D' was included to indicate application of rhodamine dye tracers needed to determine the effect of tank modifications on hydraulic efficiency. Tanks D and D' were identical except for a slightly lower flow in Tank D and the arrangement of the diffusion

tubes. Transverse aeration tubes had been installed in Tank D in hopes of reducing short circuiting. Tank D' had diffusion tubes running parallel and along one side of the tank. The transverse tubes increased rather than inhibited short circuiting.

## DISCUSSION

These tracer methods were devised to establish detention times of liquids and solids in an activated sludge sewage treatment plant. Other possible applications include other waste and water treatment plant processes, silt tracing in rivers and reservoirs, suspension tracing in lagoons, and any number of sludge handling processes.

## SUMMARY AND CONCLUSIONS

1. Iron-59 radioisotope may be used as a reliable tracer to determine the behavior of particulate matter in sewage suspensions.
2. Iron-59 almost completely adheres to particulate matter when introduced into a sewage suspension.
3. When using iron-59 as a tracer in systems which recirculate solids, an excessive tailing effect may be expected on the dispersion curve unless the recirculated radioactivity is measured and subtracted.
4. Radiotracer recovery may best be determined by counting samples in a laboratory with low background instruments under controlled conditions of counting geometry and efficiency.

5. Operation of center feed, radial flow, final sedimentation basins with a sludge blanket prevents short circuiting of mixed liquor to the return sludge outlet.
6. Particulate matter in a sewage suspension can be expected to travel faster than the liquid portion through both the clarification and the aeration system.
7. Rhodamine dye is a satisfactory tracer for determining liquid detention in waste treatment processes.
8. Although many aeration basins are designed on the basis of theoretical plug-flow, this condition is seldom, if ever, attained.

## ACKNOWLEDGMENTS

Appreciation is expressed for the cooperation of municipal personnel in the various cities where tracer studies were conducted: Messrs. William N. Wells and Don Vacker of the San Antonio Sewage Treatment Plant; Mr. C. H. Scherer, Water Reclamation Superintendent, Amarillo, Texas; Mr. David Conant, Jr., Manager, Mansfield, Ohio, Sewage Treatment Plant; Mr. C. H. Hawthorne, Superintendent, Back River Sewage Works, Baltimore, Maryland; Mr. John Hennessey, Superintendent, Division of Sewage Treatment, Pontiac, Michigan.

Special recognition is extended to Mr. Richard Stoms, U. S. Public Health Service, Cincinnati, Ohio, and Mr. Bruce W. Maxwell, Research Geologist, Robert S. Kerr Water Research Center, Ada, Oklahoma, for assistance in carrying out the initial radioisotope study.

The authors are also indebted to Mr. J. W. Keeley, Chief, Ground Water Research Program, Robert S. Kerr Water Research Center, for assistance and advice in the preparation of this report. Messrs. B. L. DePrater, F. M. Pfeffer, M. L. Cook, R. L. Cosby, and B. D. Newport, all of the Robert S. Kerr Water Research Center, Ada, Oklahoma, were instrumental in carrying out the field portion of these investigations.

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## APPENDIX II-NOTATION

The following symbols are used in this paper:

$A$ = surface area of detector, in square inches;

$A_I$ = radiation reaching the detector;

$A_v$ = volume specific activity;

$C$ = effluent tracer concentration at any time t;

$C_o$ = total tracer concentration averaged over the total volume of the tank;

$E$ = counter efficiency;

$E_{95}$ = the counting error at the 95 percent confidence limit in cpm;

$h_1$ = inside radius of a hemispherical sample;

$h_2$ = outside radius of a hemispherical sample;

$N_{06}$ = count rate of the background, in cpm;

$N_{S+BG}$ = count rate of the sample plus background, in cpm;

$R$ = calculated radius of a spherical detector;

$r$ = distance from source point in sample to the detector,

$t_{BG}$ = counting time of background, in minutes;

$t_{S+BG}$ = counting time of sample plus background, in minutes;

$t_1$ = time of first tracer appearance in the effluent;

$t_m$ = mean detention time;

$t_p$ = modal detention time;

$t_{10}$ = time of 10 percent of tracer passage;

$t_{90}$ = time of 90 percent of tracer passage;

$T$ = theoretical detention time (volume per flow rate);

$\mu$ = gamma absorption coefficient in water; and

$y$ = detectable radiation yield per disintegration.